# Soil organic matter changes resulting from tillage and biomass production

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Because soil is a limited resource, agricultural production is dependent on improving soil quality. Improved soil quality also has an impact on water use, as high quality soil more effectively collects and stores water, reducing the need for irrigation.

Intensive use of soil throughout history has led to depletion in soil quality, leading in turn to reduced yields because of the consequent reduced organic matter. Recognizing the lessons of history, scientists at research stations such as Rothamstead in England; Pendleton, Oregon; Champaign, Illinois; and Columbia, Missouri, began long-term studies on the effects of crop rotation, crop fertilization, manure additions, and residue management on the productivity and organic matter of cropped soils. In general, it was found that soil cultivation caused a decline in organic carbon content (which constitutes about half of the organic matter), or at best stabilized organic matter, even with heavy manure treatment, as long as conventional tillage continued.

In the 1960s and 1970s, many investigators noted that tillage made soils more erodible, and that crop residues left on the surface were highly effective in reducing erosion. The introduction of more and better herbicides gave farmers and researchers an economically feasible alternative to tillage for weed control, and no-till crop production became possible. Some researchers wondered whether surface-applied lime, fertilizer, and organic matter would penetrate the soil to where roots could reach them, and so they analyzed for them as a function of depth in the soil in long-term no-till studies.

Edwards et al. (1988) found, in their study carried out near Coshocton, Ohio, that organic matter was slightly less in the 3 to 6 in (7 to 15 cm) depth after 20 years of no-till, but that there was a substantial increase of organic matter in the top 3 in (7 cm). The sum of the net carbon at both soil depths showed that continuous no-till management resulted in an increase of about 23,000 lbs of organic matter per acre (26,000 kg/ha). Late winter application of cattle manure on both tillage systems may have affected soil carbon; however, these effects were not quantified.

In Georgia, Langdale et al. (1992) showed that no-till management of sorghum coupled with a winter cover crop (crimson clover) increased soil organic matter content by an average of about 2,000 lbs/ac/yr (2,270 kg/ha/yr) over conventional tillage. Most of this increase was in the top 0.6 in (15mm) (Figure 1). Their study included different levels of prior erosion, tillage, irrigation, and cover crop treatments, which gave them a broad range of grain, crop residue, and cover crop biomass production. They noted that no-till plus a winter cover crop increased infiltration, reduced evaporation, and increased the time when there was adequate water for optimum sorghum growth during the summer months. They also determined that increased infiltration and decreased evaporation in the no-till plots were the result of crop residue on the surface and high organic matter in the top 0.6 in (15 mm) of the soil.

When shallow tillage was carried out in early 1988 (Figure 1), surface residues and organic matter were mixed through the top 3.2 in (80 mm) of soil. In the first year of tillage, there was a 2,000 lb/acre (about 2,270 kg/ha) decrease in organic matter, compared to an average 2,000 lb/acre/year increase during the previous five years when there was no tillage.

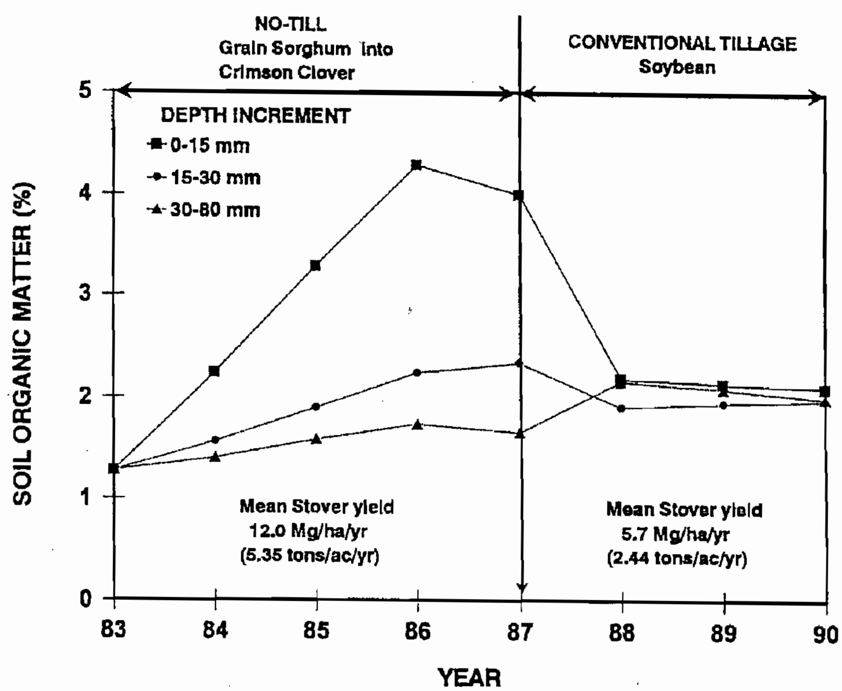


**Figure 1. Effects of tillage and winter cover crop on organic matter content near the soil surface (Langdale et al.; Bruce et al.)**

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However, Langdale et al. agreed with Mielke et al. in concluding that the detrimental effects of tillage on organic matter were not just in the reduction in total organic matter, but were associated with mixing the organic matter that had been concentrated in the top 0.6 in (15 mm) of soil. This mixing moved most of the organic matter out of the top 0.6 in of soil where it could substantially affect infiltration and evaporation to greater depths in the soil, where it does not appreciably affect water-use efficiency. Developing high organic matter content in the immediate soil surface increased infiltration and decreased evaporation to sufficiently increase water-use efficiency.

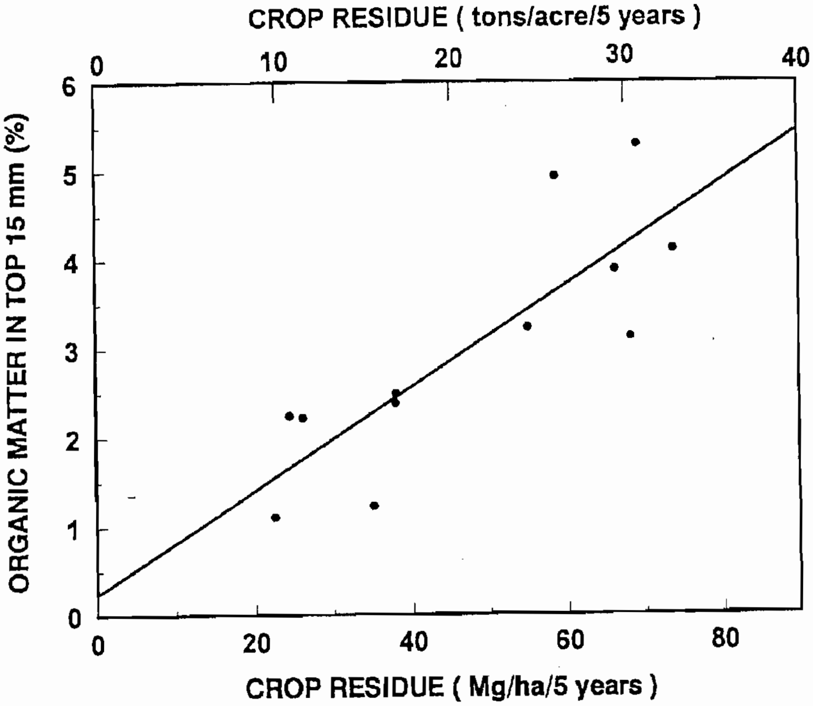



**Figure 2. Relation of organic matter in top 15 mm of soil to crop residues left on surface during this 5-year study at Watkinsville, GA (Langdale et al.)**

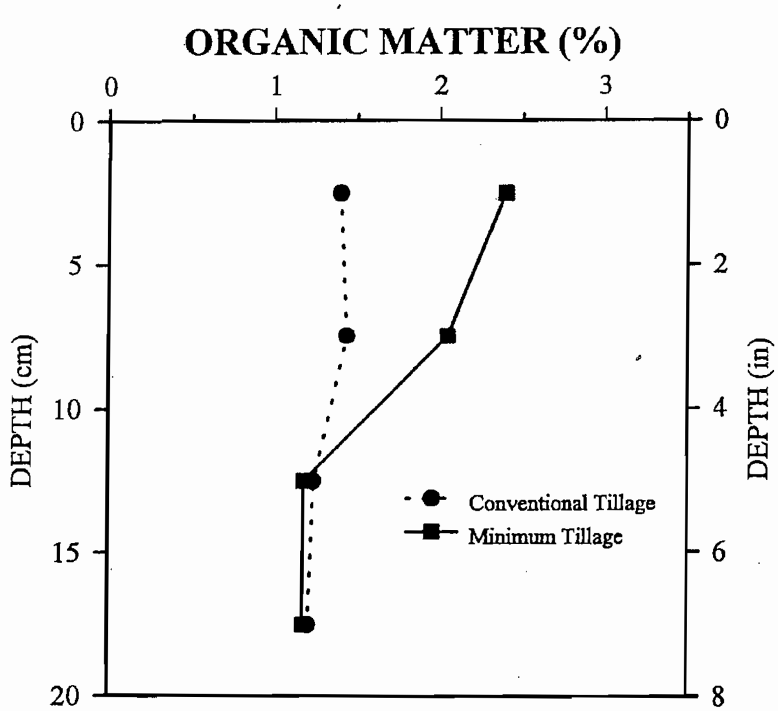



**Figure 3. Residual organic matter after 10 years of corn-wheat-soybeans-wheat rotation at Crossville, AL (Edwards et al. 1992)**

Langdale et al. also evaluated the effects of various management factors on organic matter accumulation in this layer. As expected, avoiding tillage was the primary prerequisite. However, as shown in Figure 2, increasing the amounts of crop residue (including winter cover crop residue) left on the soil during the five-year study was a major factor in increasing the organic matter in this layer, which plays such a major role in determining infiltration and subsequent water-use efficiency.

In northern Alabama, Edwards et al. (1992) compared conventional tillage, including moldboard plowing, with conservation tillage in which there was only a light disking once a year. Rotations were corn-wheat-corn-wheat and corn-wheat-soybean wheat, in which the winter wheat was not harvested but used as a cover crop. Organic matter contents in the soil after 10 years of the corn-wheat-corn-soybean rotations are shown in Figure 3 as a function of depth for the conventional and minimum tillage treatments. The light disking used once a year to prepare for seeding with a conventional drill helped move some of the crop residue and residual organic matter down into the 2- to 4-inch layer of the soil. During this 10-year study, conservation tillage treatments in the corn-wheat-soybeans-wheat rotation accumulated organic matter at a rate of about 1,700 lbs/ac/yr (about 1,900 kg/ha/yr) faster than in the respective conventional tillage treatments.

Studies where organic matter changes were monitored under no-till or conservation tillage treatments showed that rates of organic matter accumulation in soils ranged from near zero to 2,000 lbs/acre/year (0 to 2,300 kg/ha/yr). The higher rates were commonly associated with cooler climates or were in southern areas when winter cover crops supplemented the crop residues that were ultimately converted into soil organic matter. Corn residues return more biomass to the soil than soybean, and soybean residues decompose faster because of their lower C:N ratio. These factors resulted in higher rates of increase in soil organic matter when corn was grown.

In general, the rate of organic matter accumulation or loss depends on the rate at which biomass is added to the soil minus the rate at which erosion and biological oxidation are removing organic matter from the soil. Both erosion and biological oxidation, which reduce organic matter in topsoil, are accelerated by tillage as shown schematically in Figure 4.

## Tillage methods and carbon loss

Tillage methods have a pronounced effect on distribution of crop residues within the soil and can affect soil carbon loss. Vertical distribution within the soil has been suggested as a factor in many soil biological processes that affect the soil carbon level. Staricka et al., found moldboard plowing incorporated crop residue to 11 in (28 cm), chiseling and disking to 4 in (10 cm) and the untilled left residue on the surface. Tillage buried the residue but did not uniformly distribute it throughout the disturbed depth. Instead, it left a clustered distribution of crop residues that had a distinctly higher porosity than the soil in general. This suggests the potential for increased leaching. If these same porous areas are continuous to the soil surface, then oxygen can move in and carbon dioxide move out to enhance biological oxidation of soil carbon.

Because water runoff and wind and water erosion have generally not been measured in the long-term management studies, organic matter decreases attributable to erosion and biological oxidation were not generally definable. Most of our judgements about the relative importance of these factors were influenced by early studies such as those of Rovira and Greacen (1957) on effects of tillage on gaseous carbon ($CO_2$) loss. These studies were designed to measure the effects of tillage alone, and avoided incorporation of fresh crop residues, because of their obvious major effect on $CO_2$ production. They found that by disrupting the soil, they could release about 20 lbs of carbon/ac. Erosion, which commonly removes 5 tons of topsoil/ac/yr, which in the Midwest often has about 2 percent organic carbon, can cause a carbon loss of 200 lbs/ac/yr. Consequently, the potential for reducing rates of oxidative carbon loss as a result of tillage reduction appeared practically negligible.

However, recent studies involving tillage and associated incorporation of crop residues in the field show major interactions that are changing this point of view. Reicosky and Lindstrom (1993) used a large chamber and gas exchange techniques to measure effects of fall tillage methods on the $CO_2$ flux from a Hammerly clay loam (fine, loamy frigid Aeric Calciaquoll) in the northern Corn Belt. The preceding crop was wheat, and the soil was tilled using several tillage methods, including conventional fall moldboard plow.

During the 19 days of their study, moldboard plow tillage (MP) released the greatest amount of $CO_2$ (Figure 5). Differences in $CO_2$ losses appear to be related the degree to which soil is fractured and left in a loose condition that facilitated movement of $O_2$ into and $CO_2$ out of the soil. The moldboard plow treatment buried all the residue and left the soil in a rough, loose, and open condition. This combination of factors promoted high $CO_2$ loss from

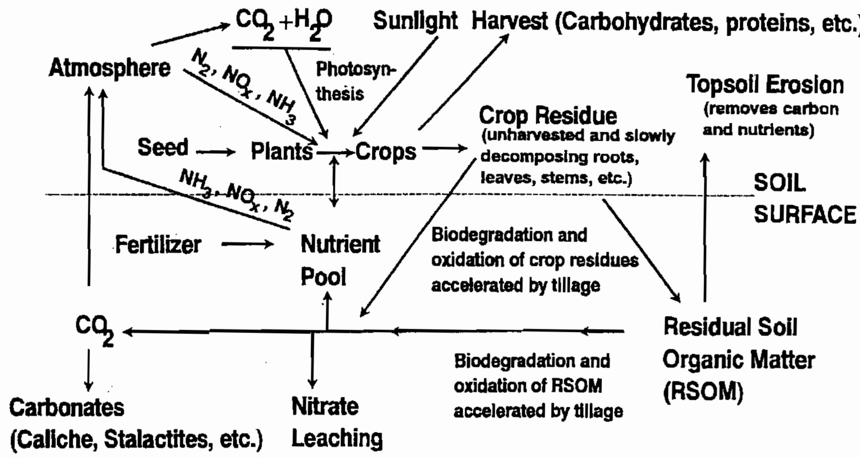



**Figure 4. Carbon and nutrient cycling in cropping systems**

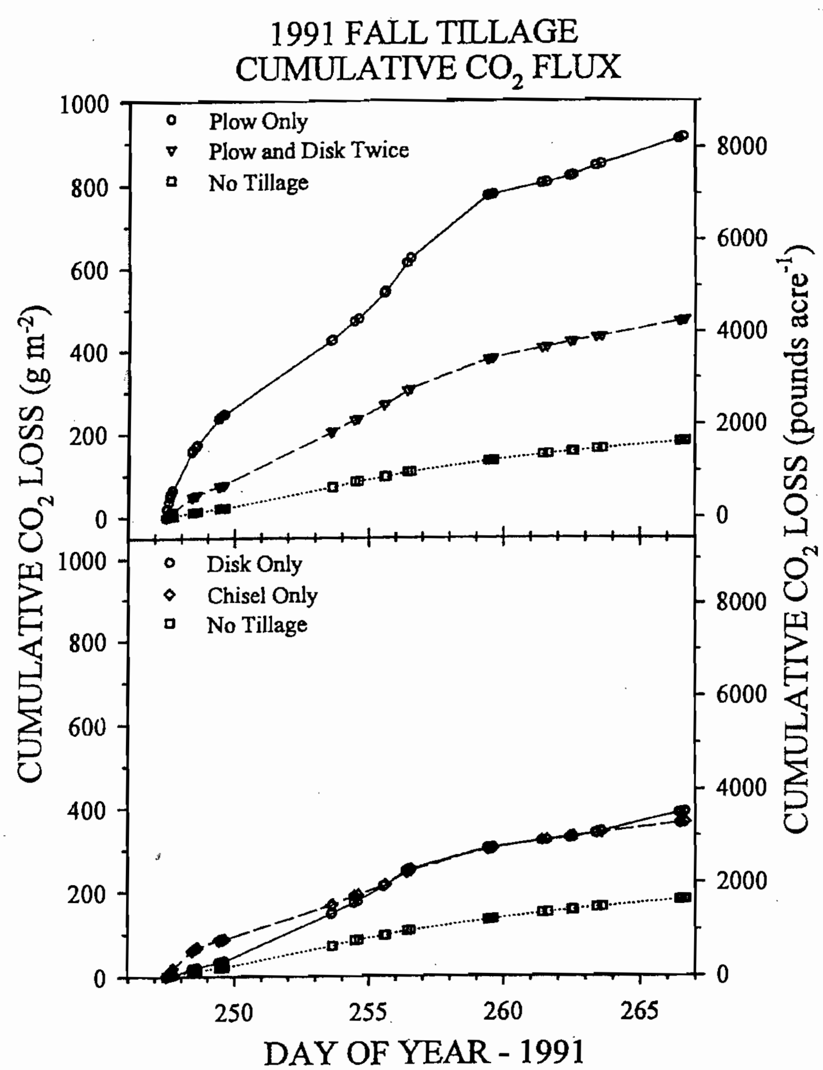
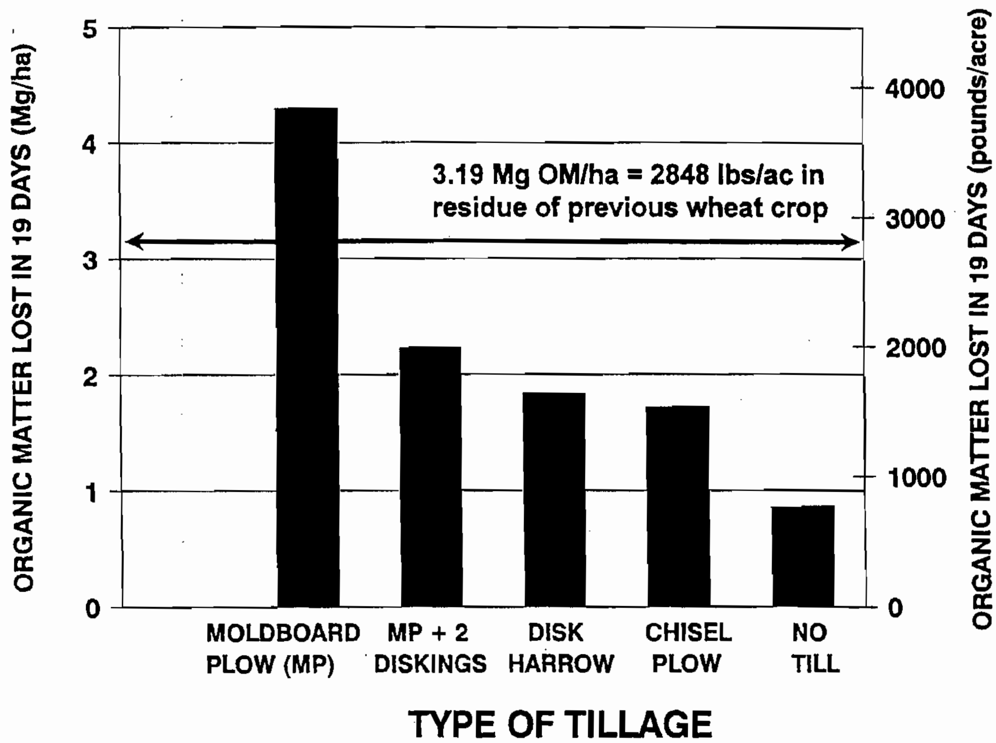



**Figure 5. Cumulative $CO_2$ flux as affected by different methods of tillage (Reicosky and Lindstrom 1993)**

Figure 6. Total organic matter lost in 19 days after tillage relative to the amount of organic matter in residue from the previous wheat crop (Reicosky and Lindstrom 1995)




the plowed surface. Where the moldboard plowing was followed by two disk harrowings the surface roughness and porosity were reduced and wheel traffic packed the aggregates and clods together restricting microbial activity and the degree to which fungal hyphae could extend and $O_2$ and $CO_2$ could diffuse through the soil.

In Figure 6, $CO_2$ amounts released during 19 days (Reicosky and Lindstrom 1995) are compared to the C in the residue (tops and roots of the previous wheat crop). Accepting the common approximations that 59 percent of the soil organic matter is carbon and that 45 percent of the wheat residue is carbon then the carbon equivalent of the 3680 lbs of wheat residue/ac (4.12 Mg of wheat residues/ha) is about 2,800 lbs OM/ac (3.15 Mg of soil OM/ha). Carbon released as $CO_2$ during the 19 days following the MP, MP+DH2, DH, CP, and NT treatments would account for 134, 70, 58, 54, and 27 percent, respectively, of the C in the current years crop residue (Figure 6).

The fact that considerably more C was released as $CO_2$ from the plowed plots than the C in the previous crop residue and roots indicates that substantial amounts of residual soil organic matter were included in the preceding biologic oxidation. Nineteen days after plowing at least half of the straw that was incorporated was still visible and not completely decomposed. This indicates that more than half of the $CO_2$ emitted from the plowed plots came ultimately from residual soil organic matter. This amounts to about 1,800 lbs of residual soil organic matter lost per acre (2.1 Mg/ha) in 19 days which is two orders of magnitude higher than the rates of C loss reported by Rovira and Greacen (1957).

After the initial flush of $CO_2$, the difference is apparently a result of the stimulation of microbial activity by incorporation of "fresh" crop residues and oxygen. The effect of plowing and incorporating fresh crop residue on the biological oxidation of the residual organic matter is similar to opening the air supply and stirring kindling into the smoldering coals of an old coal stove fire box. In both cases the oxidation is accelerated by the improved oxygen supply and accessibility of new easily oxidizable material, resulting in further substantial oxidation of the residual carbon in the system.

Since the organic carbon lost as a result of 5 tons/yr of erosion of soil with 2 percent organic carbon is about 200 lbs/ac (i.e.about 340 lbs of organic matter/ac) and the amount lost by biological oxidation of crop residues can be 2000 or 3000 lbs/ac/yr, it appears that the dominant cause of organic carbon reduction in our soils has generally been tillage, especially when that tillage included moldboard plowing. In some cases in the past where there has been extreme erosion (i.e., over 50 tons/ac/yr), erosion has removed more carbon than biological oxidation of carbon induced by plowing.

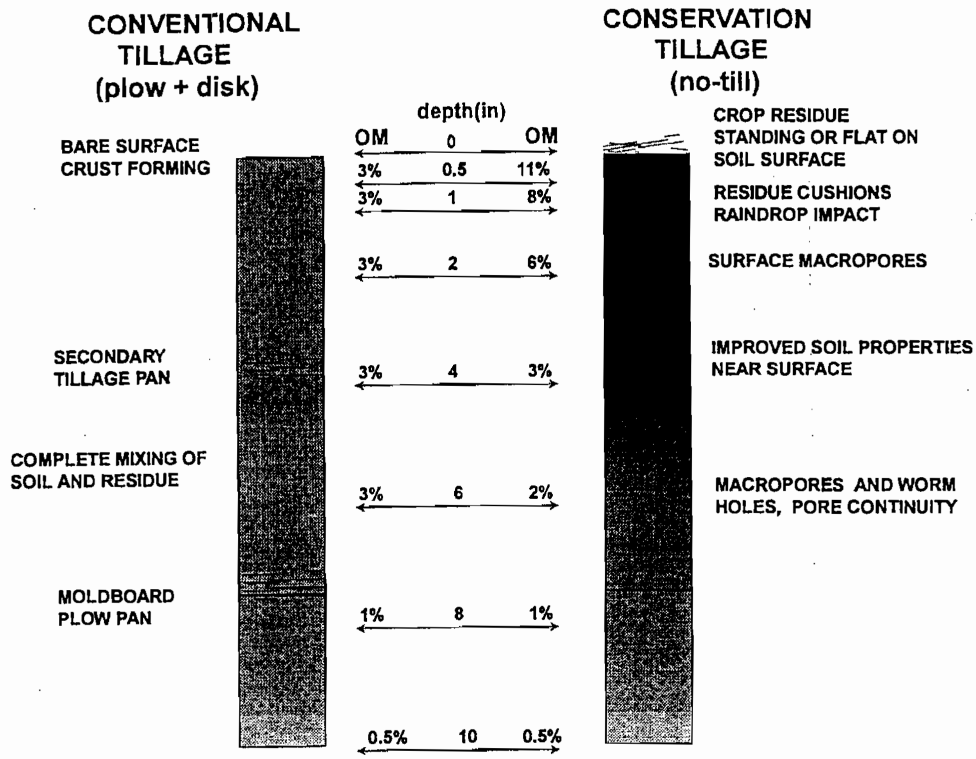
However, practices built into conservation plans by farmers and advisers for highly erodible land now generally aim to keep erosion below 5 tons of soil/ac/yr. Research has shown that the most cost effective erosion control practices involve keeping crop residues on the surface and reducing tillage as much as possible.

**Table 1. Effects of tillage, crop rotation, and time on rates of residual soil organic matter change in 6-inch acre furrow slice**

| Type of Tillage | Crop Rotation | Location, Time and Reference | Rates of Residual Soil Organic Matter Change (lb/ac/yr) |
|---|---|---|---|
| No-till | Continuous corn 3 t manure/yr | Coshocton, OH 20 yrs Edwards et al. (1988) | + 890 |
| No-till except for light disking once a year in preparation for seeding | Continuous corn with wheat cover crop | Crossville, AL 10 yrs Edwards et al. (1992) | +1700* |
| | Corn-soybean with wheat cover crop | | +1360* |
| | Continuous soybean with wheat cover crop | | +1020* |
| No-till | Sorghum with crimson clover as winter cover | Watkinsville GA 5 yrs Langdale et al. (1992) | +2000 |
| First year till after 5 yrs no-till | Soybean | Watkinsville GA I yr Langdale et al. (1992) | -2000 |
| No-till | " | Lexington KY II yrs Mielke et al. (1986) | +760* |
| No-till | " | Etwood IL II yrs Mielke et al. (1986) | +550* |
| No-till | " | Waseca MN II yrs Mielke et al. (1986) | + 80* |
| No-till | " | Lincoln & Sidney NE 11 yrs Mielke et al. (1986) | +510* |
| No-till | Continuous corn | Lexington, KY 1972-1992 Ismail et al. (1994) | +660* |
| Moldboard plow+ | Continuous corn | Urbana, IL 1904-1923 Peck (1989) Morrow Plots | -670 |
| " | Corn-oats-hay | " | -640 |
| " | Corn-oats | " | -740 |
| Moldboard plow+ | Continuous corn | Urbana, IL 1963-88 Peck (1989) Morrow Plots | -190 |
| " | Corn-oats-hay | " | -170 |
| " | Corn-soybean | " | -220 |
| Moldboard plow+ | Annual or wheat fallow no N applied | Pendleton, OR 1881-1931 Rasmussen & Parton (1994) | -61 |
| " | Wheat/fallow no N applied | Pendleton OR 1931-1986 Rasmussen & Parton (1994) | -168 |
| Moldboard plow+ | Wheat/fallow no N, fall burn | Pendleton, OR 1931-1986 Rasmussen & Parton (1994) | -185 |
| " | Wheat/fallow 40 lbs N/acre/crop | Pendleton, OR 1931-1986 Rasmussen & Parton (1994) | -118 |
| " | Wheat/fallow 1 t pea vines/acre/crop | Pendleton, OR 1931-1986 Rasmussen & Parton (1994) | -87 |
| " | Wheat/fallow 10 t manure/acre/crop | Pendleton, OR 1931-1986 Rasmussen & Parton (1994) | +27 |
| Moldboard plow | Continuous wheat 6 t manure/yr | Columbia, MO 1915-1937 Wagner (1989) Sanborn Plots | -510 |
| " | Continuous wheat 6 t manure/yr | Columbia MO 1937-1967 Wagner (1989) Sanborn Plots | 0 |
| " | Continuous corn 6 t manure/yr | Columbia, MO 1915-1937 Wagner (1989) Sanborn Plots | -550 |
| " | Continuous corn 6 t manure/yr | Columbia, MO 1937-1967 Wagner (1989) Sanborn Plots | -30 |
| " | Continuous wheat | Columbia, MO 1915-1937 Wagner (1989) Sanborn Plots | -570 |
| " | Continuous corn | Columbia, MO 1915-1937 Wagner (1989) Sanborn Plots | -220 |
| " | Continuous wheat | Columbia, MO 1937-1967 Wagner (1989) | -20 |
| " | Continuous corn | Columbia, MO 1937-1967 Wagner (1989) | 0 |

*Estimates based on organic matter content in no-till plots minus organic matter content in tilled plots and assuming rate of change in tilled plot is negligible. (see text for rationale)

Figure 7. Schematic representation of soil profiles after long-term conventional and conservation tillage




As a result of this research and farmer experience, more than 75 percent of the farmers with highly erodible lands have chosen reduced tillage and surface residue as the primary component of their plan to achieve conservation compliance.

The above findings indicate that keeping crop residues on the surface and reducing tillage not only reduces erosion, but also reduces the physical release of $CO_2$ and biological oxidation of soil carbon, which has been a less obvious, but usually the greater cause of organic matter depletion in soils.

Evidence that intensive tillage decreases soil organic matter has been accumulating for thousands of years. The magnitude of gaseous C loss after moldboard plowing explains why this C loss continues in many agricultural ecosystems with conventional tillage.

Moldboard plowing not only fractures, inverts, and opens the soil, allowing rapid $O_2$ and $CO_2$ exchange, but also incorporates crop residues into the soil, which feeds a microbial "population explosion." With conservation tillage, most crop residues are left on the soil surface with only a small portion in intimate contact with soil moisture and available to the microorganisms. As a result, the residues decompose more slowly. Some biological oxidation is needed to get other benefits of microbial activity (e.g., mucilage, gels for stabilized aggregate formation, controlled release of nutrients through mineralization). The key is to have biological oxidation at a "controlled rate" to maintain optimum soil properties as in conservation tillage. On the other hand, plowing under the residue places the food source for the microbes in contact with water and nutrients from the soil and maintains oxygen supplies through the large pores of freshly tilled soil. The expanding populations of microorganisms feed on both fresh residue and residual soil organic matter exposed by tillage to those organisms and their enzymes, which initiate organic matter degradation and cause oxidation of the carbon to $CO_2$.

## Effects of crop rotations and tillage on soil organic matter

Changes in organic matter generally are less than one or two percent per year of the total organic matter in soil. Consequently, the effects of crop rotations and tillage on soil organic matter become significant only after several years. Because the rates at which organic matter is changing in conventional tillage treatments is generally fairly slow, the differences between the organic matter contents of no-till and conventional treatments are often reasonable estimates of the increase in organic matter in the no-till plots.

Estimates of this type are indicated by asterisk in Table 1 which summarizes rates of residual organic matter change in management systems cited in the previous discussion.

However, since the conventional tillage was probably causing rates of organic matter loss of 0 to 100 lbs/ac/yr, the asterisked estimates of organic matter increase rates in Table 1 are probably that much greater than actual rates.

In general, it is practically impossible to increase organic matter where moldboard plowing is taking place. Massive additions (6 to 10 tons/ac/yr) of manures in addition to crop residues plowed into soils are able to cause small increases for a few years, but leveling off or slight decreases follow. No-till, in northern areas involving corn is able to increase soil organic matter. In southern regions where wheat, rye, and legumes can be grown during the winter months and their residues left on the surface with those of the summer crops, increases in residual soil organic matter contents of up to 2,000 lbs OM/ac/yr are possible. Where very light tillage (shallow disking for seedbed preparation) is used and winter cover crops are adding large amounts of residue, somewhat lower, but highly significant increases in organic matter have occurred. These increases in organic matter will continue for at least 10 years. There are indications that the rates of increase become smaller as longer time periods are involved.

## Increasing residual soil organic matter

Figure 4 outlines major factors involved in the cycling of carbon and nutrients in crop production systems. The benefits derived from increasing residual soil organic matter (RSOM) are substantial. Let's summarize the practices that help achieve that increase. Increasing the amount of crop residues (including cover crops) left in and on the soil increases the supply of carbon from which RSOM is built (Figure 4). Avoiding erosion of carbon and nutrients in rich topsoil can commonly be achieved by reducing tillage and/or leaving crop residues on the surface to protect the soil. This same reduction of tillage also reduces the rate of biodegradation and oxidation of crop residues and RSOM, thus allowing them to accumulate on and in the soil.

Technologies now available that allow us to increase residual soil organic matter raise questions of how much we can increase RSOM and the extent to which efforts to achieve this increase will be a good investment. Following the cycle outlined in Figure 4, it is apparent that making optimum use of sunlight by having photosynthesizing crops on the surface for as much time as possible boosts the production of biomass and, subsequently residues for soil carbon increase. The practical limiting factors include water supply and freezing weather.

Economic considerations play a major role in residue management. The biomass that farmers can afford to leave on fields is dependent on the value on the market of crop residues and cover crops as fodder and fuel. In many places in the United States, the value of wheat straw and corn stalk stover on the market is less than the baling and hauling costs, so there is no cost associated with leaving it in the field. However, winter cover crops such as legumes, and even rye and winter wheat have protein contents high enough to have values of $40 to $60 /dry weight ton. Because cutting, baling, and hauling costs, (or silaging costs) are generally in the range of $15 to $25/ton, where the farmer can use or market the winter cover crops as fodder or silage, a net return of $20 to $30/ton can often be realized. Where he can produce and harvest an average of 3 dry weight tons of harvestable winter cover crop (i.e., Figure 2) and can harvest it for a net return of about $25/ton, this can be a substantial portion of the net return from that land. Most farmers are not likely to leave it in the field to supplement the crop residues from the previous summer's crop.

Another potential market for biomass that may decrease the amounts of crop residues available to build or maintain our soils is the use of dried crop residues as a fuel in power plants generating electricity. High protein contents do not add to the value of fuel stocks for these generators but low water contents would be necessary to get good power yields. Current estimates are that such power plants could pay between $40 and $50/ton for dry crop materials. These alternative uses for lignocellulosic biomass may substantially reduce the biomass available for soil protection and improvement. Current estimates are that it would require about 1,200 million tons of dry biomass/year to provide the energy needed by the United States (assuming an energy conversion efficiency of 30 percent). If our lands used for this purpose produced an average of 4 dry weight tons per acre, that would require 300 million acres of land! Other sources of energy will undoubtedly help supply our future needs. However, the Department of Energy is developing the use of biomass for renewable energy into an economically feasible possibility. We in agriculture should consider the optimum use of our crop residue biomass for soil improvement and long-term sustainability while the market value of that biomass is still low. Ultimately, the use of crop residues will be determined by a complex interaction of economic, political and environmental issues that balance requirements for food and fiber production and renewable energy sources.

In the past we have generally considered our best soils to be those that nature has built during long tenure in grass and have not been degraded by extended use in production agriculture. The extensive root systems of grasses in concert with mulch on the surface from unharvested leaves and stems has built residual organic matter to high levels as would be expected from considering the factors involved in Figure 4. Tillage is not necessary in many production systems because herbicides now provide alternatives for weed control. Drills and planters can get good stands without tillage for seed bed preparation. Consequently it is no longer necessary to till soils and thereby increase potential for accelerated erosion and biological oxidation. Further consideration of Figure 4 and what can be done in current production systems compared to the historical grass lands leads to the conclusion that we could substantially increase biomass production. Fertilizer additions, increased atmospheric $CO_2$ concentrations, improved species and crop rotations, including winter cover crops will all contribute.

Crop water-use efficiency probably decreased as grass lands were converted to tilled production systems because we increased bare soil surface evaporation. However, there appear to be good possibilities that water-use efficiency can be increased where conventional tilled production systems are converted to conservation tillage. Consequently, under well managed conservation systems, we have an opportunity to increase the organic matter content of our soils. There is reason to believe that well managed, long-term conservation systems growing grain crops could eventually raise residual organic matter in soils to levels in natural prairie ecosystems and possibly higher.

As we continue to collect data and evaluate the relative merits of conventional till (plow and disk) versus conservation tillage (no-till), a clearer concept emerges as illustrated schematically in Figure 7. Long-term (> 10 years) analysis of both systems enables certain generalizations. Most notable is the OM distribution in conservation tillage that is substantially higher in the surface layer and gradually decreases to the same OM content as the conventional till below the plow depth. This high OM content near the surface and the surface residue are the main contributors to the improved surface soil properties that increase infiltration, decrease erosion, decrease evaporation, and generally improve precipitation use efficiency.

Each ton of organic matter built back into our soils contains about 100 pounds of nitrogen and significant amounts of other nutrients that mineralize slowly under no-till. As soil temperature rises in the spring and early summer, the crops grow rapidly and the microorganisms become more active, using the carbon for energy and mineralizing nutrients so they become available to the crop. This normal synchronization of supply with need for nutrients is disrupted by events such as fall plowing prior to spring planting, which accelerates oxidation of the carbon and converts organic nitrogen to nitrate when it is not needed, leaving it vulnerable to leaching during the cold period when precipitation commonly exceeds evapotranspiration. After heavy rains have leached nitrates out of the root zones, the high soil water content often stimulates earthworm and microbial activities that oxidize the carbon and mineralize significant amounts of the nitrogen from the RSOM, making the resulting $NH_4$ and $NO_3$ available to the plants. This organic matter in our soils is like an insured bank account that can be drawn upon for sustenance in times of need. Optimizing the rate of organic matter increase in our soils will cost a few dollars in terms of seed for cover crops and nitrogen fertilizer to increase biomass production. Choosing cash and cover crops that have the capability to generate large amounts of biomass and application of manures and other organic wastes on the surface will also help increase residual organic matter. However, as studies in Minnesota, South Dakota, North Dakota, Ohio, Kentucky, Tennessee, Georgia, Alabama, Mississippi, Illinois, Nebraska, Colorado, Texas, and Oregon have shown, a prerequisite for sustaining or increasing organic matter content of most soils is minimization or elimination of tillage.

## Summary

In summary, a clearer understanding of residual organic matter and how it can be maintained and increased is unfolding. Productivities of soils are strongly related to their soil organic matter contents. The soil OM levels are controlled by many factors, which can be summarized by a simple C mass balance, i.e.,

carbon input–carbon output = net gain.

The amount in is controlled by the level of residue input, largely determined by crop choice, fertilization, and climate. Management can control the crop selection, rotation system, and fertilization. While the managers cannot control the climate per se, they can decide the dates of planting and harvest and, in some cases, can irrigate to achieve the needed, biomass. The amount of OM leaving the soil system is controlled by crop grain and residue removal, rate of biological oxidation and rate of soil erosion. The latter two mechanisms of soil organic matter loss are substantially reduced if tillage is reduced or eliminated. The recently identified large gaseous losses of soil carbon following moldboard plowing compared to the relatively small losses with no-till have shown why crop production systems involving moldboard plowing have decreased soil organic matter and why no-till crop production systems are stopping and reversing that trend.

In the past when low-cost sources of nutrients were not available and nutrients were often the limiting factor in crop production, tillage accelerated degradation of organic matter increased the supply of available nutrients and crop production. Intensive tillage, such as moldboard plowing, provided this immediate and obvious short-term return, but it was also depleting our basic resource—soil organic matter. More rapid depletion of OM also reduced the ability of these soils to absorb and hold precipitation for crop use. Soils also become more susceptible to increased erosion by wind and water. No-till production systems reduce the rate at which organic matter is disintegrated into its basic constituents and used by microorganisms and mesofauna (e.g. earthworms) as a source of energy and body parts. This reduction of the rate of organic matter disintegration leaves more residues on our soil surfaces and more organic matter in the upper portions of our topsoil where they are strategically situated to protect the soil from erosion and increase crop production per unit of precipitation received. However, no-till production systems with their increasing organic matter and water-use efficiency do not always provide all the needed solutions to our problems. Cooler soil in the spring, reduced stands, slower germination, and increased incidence of some insects, diseases, and weeds have been problems in some areas. Many of these problems are being solved by new and adapted equipment, crop rotation, and selection of varieties better suited to no-till systems. However, there are many opportunities for further improvement of man's recent versions of this most ancient system.

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